BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 07085

SUBJECT: Evolution of the Nimbus Spacecraft System Case 105-4

DATE: July 28, 1970

FROM: J. P. Jamison

ABSTRACT

To provide a basis for planning future space science and applications programs, this memorandum examines the evolution and performance record of a representative class of unmanned spacecraft, i.e., Nimbus. It determines (1) trends in the development of unmanned spacecraft technology and (2) the role that might have been played by the integrated program capability in carrying out such a hitherto unmanned program. The integrated capability is assumed to include a low cost transportation system capable of transporting automated spacecraft to and from the Nimbus orbit and capable of providing on-orbit servicing, and Nimbus-type spacecraft configured to be compatible with transportation by shuttle and on-orbit servicing.

The currently approved program will place six Nimbus research and development spacecraft in orbit over a period of about 9 years. Inasmuch as spacecraft system capabilities were significantly increased in Nimbus III, the series can be considered as comprising two generations of spacecraft mounting increasingly sophisticated meteorological experiments. Succeeding spacecraft have been upgraded by increasing subsystem life, improving data systems, and increasing sensor complement. It appears that Nimbus F, to be launched in 1973, may be the last of the series; the relatively large antennas required for microwave experiments exceed the space available in the Nimbus earth-viewing base area.

Had the integrated program capability assumed above been available, the achievements of the automated Nimbus program could have been realized by the manned program at a cost which appears to be quite competitive. More importantly, the capability to install new sensors at regular intervals, such as every six months, would have brought experimental sensors to a state of operational readiness at an earlier date.

(NASA-CR-113124) EVOLUTION OF THE NIMBUS SPACECRAFT SYSTEM (Bellcomm, Inc.) 19 p

N79-72133

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FF No. 602 (PAGES) (CODE)
CR-113124
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
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MEMORANDUM FOR FILE

Introduction

An issue that is raised with increasing frequency in the planning of future space programs deals with the technical interface between manned and unmanned projects. This is attributable to a great extent to the adoption as a focus for future development of the integrated program capability identified in the Space Task Group Report. Specifically, the Space Task Group foresaw an operational phase in earth-moon space in which "continued exploration of science and applications would be emphasized, making greater use of man or man-attendance as a result of anticipated lower costs for these operations." One of the major problems in planning such future programs is a general lack of understanding of how competitive or compatible manned and unmanned systems will be and of the role which manned systems will fulfill in hitherto unmanned space science and applications activity.

The purpose of this memorandum is to examine the evolution of the various systems and the performance record of a typical class of unmanned spacecraft, i.e., Nimbus, to determine:

(1) Trends in the development of unmanned spacecraft technology.

(2) The role that might have been played by an integrated program capability in carrying out such a program.

The intent is to provide a basis for planning future space science and applications experiments.

Nimbus Program Objectives

The Nimbus research and development project, initiated in 1960 as the follow-on to TIROS in the NASA meteorological satellite program, represents a major effort to develop a versatile observatory spacecraft system to meet the R&D needs of the nation's atmospheric and earth scientists over an extended period. Nimbus was conceived as an amply-powered earth-oriented spacecraft, capable of supporting a variety of experiments designed for observation of the earth's atmosphere and for rapid transmission of the collected data. It was developed as a general-purpose platform for a variety of experiments, facilitating product improvement and evaluation by accommodating new sensor developments and by adopting improved basic spacecraft systems in successive spacecraft of the series.

The general objectives of the Nimbus program are: (1)

- Development and flight application of advanced passive radiometric and spectrometric sensors for the daily global surveillance of the earth's atmosphere to provide a data base for long range weather forecasting.

- Development and evaluation of new active and passive sensors for sounding the earth's atmosphere and mapping surface characteristics.

- Development of advanced spacecraft systems and improved ground techniques for receiving and processing meteorological data from spacecraft.

- Development of new techniques and knowledge useful for the exploration of other planetary atmospheres.

- Preparation for U.S. participation in global observation (World Weather Watch) programs by expanding daily global weather observation capability.

- Provision of a supplemental source of operational meteorological data.

Nimbus I, the first spacecraft of the family, was launched in August, 1964. The currently authorized series of flight tests runs through Nimbus F, scheduled for launch in mid-1973. The Nimbus spacecraft has demonstrated flexibility and its capability has been enhanced as the series progressed, enabling the Nimbus system to meet the demands for a meteorological research and development spacecraft for more than a decade.

Basic Design Criteria

Two significant features of the Nimbus concept were the choice of an earth-stabilized platform and the decision to use a polar orbit. This combination yields full-earth coverage on a daily basis. The basic design criteria were: [2]

- A system tailored to support the basic sensors required to measure atmospheric phenomena.
- Inherent flexibility to facilitate system and sensor modifications and evolution.
- A geometry and mass distribution that support the control system action.
- Complete global coverage on a daily basis.
- System dimensions and weight compatible with a medium sized booster system (Thor-Agena).
- Long satellite life with an initial design goal of 6 months.
- Application of current state-of-the-art to ensure system reliability and early flight capability.
- Rapid data acquisition and transmission to permit its application to weather forecasting.
- Minimum overall system cost per data point.

<u>Nimbus Spacecraft Characteristics</u>

These design criteria led to a Nimbus system with the following characteristics: (2)

- A near-polar sun-synchronous "high-noon" orbit, permitting complete daily earth coverage by utilizing a retrograde orbit of roughly 80 degrees inclination. This type of orbit provides proper illumination for the weather cameras and makes possible the pointing of the solar array to the sun by only a single axis rotation.
- Three-axis earth-stabilization, with pointing accuracy of $\pm$ 1 degree in all axes and slow (0.05 degrees per second) rotational rates.
- A 600 nautical mile altitude, chosen as a design compromise. Improved sensor resolution favors a lower altitude, while higher altitudes are required for complete earth coverage and for ground-station data readout with a minimum number of ground stations; the station at Fairbanks, Alaska has access to 75 percent of the Nimbus orbits, and is supplemented by a second station at Rosman, North Carolina

. A modular approach to spacecraft layout to permit evolution of subsystems and sensors with minimum difficulty.

. An S-band data transmission system, as well as a VHF system, to permit rapid transmission of the voluminous data.

Spacecraft Elements

The configuration of the Nimbus spacecraft is shown in Figure 1. The experiments indicated are those carried in Nimbus III. A distinctive feature of the basic spacecraft design is that it consists of three major elements. They are (1) the Sensory Ring, a 57-inch diameter toroid which provides 18 compartments to house weather data sensors and associated electronics, (2) the Solar Arrays, two large (3 x 8 feet) solar cell panels mounted on a rotating shaft that extends through the Control Subsystem assembly, and (3) the Control Subsystem, a hexagonal structure that packages the entire attitude control subsystem and includes its own thermal control. This design allows very simple and easily controlled interfaces, both mechanical and electrical, between the attitude control subsystem and the other elements.

Major Spacecraft Subsystem

The major Nimbus subsystems are briefly described below, taking notice of the growth and development of capabilities in succeeding spacecraft where significant changes have occurred.

. Attitude Control Subsystem. This subsystem is housed in a hexagonal structure 33 x 20 inches in size, which weighs 167 pounds and consumes 72 watts average d.c. power. It controls motion about the pitch, roll and yaw spacecraft axes and the Solar Array axis. Error signals are generated by horizon sensors for the pitch and roll axes, while a sun sensor and rate gyro are used for yaw stabilization. Inertia wheels in conjunction with a pneumatic gas jet system achieve one-degree accuracy in stabilization and hold angular rates to less than .05 degrees per second. The attitude control subsystem is required to:

- Point continuously toward the earth.

- Align the spacecraft and its cameras to the orbit plane so that successive photographs have a known relationship to each other, making it convenient to construct a complete pole-to-pole map of the earth's surface.

- Maintain the Solar Array pointed at the sun.
- Provide internal thermal control.
- Provide operational data to telemetry.

• Attitude Control Subsystem Development. The Solar Array drive on Nimbus I failed after 27 days of orbital operation, preventing the spacecraft from achieving its designed six month operating life. The drive stopped rotating due to excessive temperature on the rear servo motor bearing, which thickened the grease and ultimately stalled the motor. The design changes listed below were made before the second flight and have demonstrated a satisfactory solution of the problem in subsequent Nimbus spacecraft:

  - A larger servo motor was used.
  - Voltages on both phases of the motor were reduced.
  - The motor was painted black.
  - The conducting heat path from the outer bearing race to the stator was improved.
  - A thermal strap was added to the motor.

  Refinements introduced into the attitude control subsystem in Nimbus IV include the capability to reacquire the reference orientation from any attitude should some disturbance temporarily interrupt attitude stabilization and the operational use of the rate monitoring package (RMP), a high-quality rate-integrating gyro carried as an experiment in Nimbus III.

• Power Subsystem[3]

  The solar-conversion power supply consists of the solar arrays and associated electronics equipment. In Nimbus I and II, seven nickel-cadmium batteries, connected in parallel, were powered by 10,982 solar cells. The power subsystems used dissipative regulation techniques and simple battery protection circuits. Battery overcharge protection was provided by ground control of special spacecraft loads.

The power system in those spacecraft was required to provide no less than 160 watts of continuous power for a minimum mission lifetime of six months. Output voltage was 24.5 volts d.c. regulated to ± 2%.

The second generation power system design, incorporated in Nimbus III and subsequent spacecraft takes advantage of advances in power conditioning technology which permit substantial gains in terms of extended spacecraft life or increased load capability. This design makes use of nondissipative regulation techniques and automatic battery overcharge control. The 500 watt pulse-width modulated switching regulator is capable of 90% orbital efficiency, compared to 75% efficiency for the dissipative model. This increases the power available for spacecraft use from 160 to 195 watts (average) during an orbit. Nimbus III has 8 rather than 7 battery modules to support increased mission requirements. The solar arrays have been identical in Nimbus I, II, III, and IV, and the power supplies in all four spacecraft have met their specifications and performed perfectly.

Nimbus III carries the SNAP-19 Radioisotope Thermoelectric Generator (RTG), the first Space Nuclear Auxiliary Power system to be used on a meteorological satellite. Having demonstrated its capability of supplying 50 watts of regulated power, this system is now generating power full time on the spacecraft main power bus. The SNAP-19 was placed aboard NimbusIII as an experiment, and at this time nuclear power generators are not planned for the power systems of currently approved Nimbus spacecraft. RTG power sources are being evaluated against solar cell arrays to determine the optimum power supply for advanced spacecraft after Nimbus F.

- <u>Telemetry Subsystem</u> (1)

Nimbus I through III used a multimode pulse code modulated (PCM) telemetry system to transmit spacecraft housekeeping and certain experiment data at a 500 bit per second rate. In Nimbus IV the telemetry capability was enhanced by the incorporation of the Versatile Information Processor (VIP) Subsystem, which samples the output of approximately 1000 sensors and formats the data into a 4000 bit per second serial bit stream for recording or direct transmission on the beacon transmission link.

- Command Subsystem [1]

  This subsystem consists of two basic functional areas, the Command Receiver and the Command Clock, and serves the following functions:

  - Provides an accurate time base for spacecraft activities.
  - Generates a time code for transmission with spacecraft data so the time reference can be used to process data on the ground.
  - Generates standard frequencies and motor drive signals used by the various other subsystems within the spacecraft.
  - Receives, processes and stores command information from the ground and executes those commands at the determined times.

The capacity of the command subsystem has grown so that Nimbus IV has the capability to execute 512 different commands, an increase from 128 in Nimbus III [4]. Ground commands can switch components and power control for experiments and subsystems, calibrate or change experiment factors, and change modes of operation of the communications and data handling systems.

- Experiment Subsystem

Nimbus-borne experiments are housed in the sensory ring structure which is a 57-inch toroid, 13 inches tall and 8 inches deep, divided into eighteen cavities. This design has several advantages: [2]

- The sensory subsystem is a separate entity, relying only on power from the spacecraft.
- The many compartments in the ring facilitate adjusting the balance.
- A large base area is available for the interference-free installation of optical sensors and scanners.

- The cylindrical volume inside the sensory ring offers flexibility in packaging bulky equipment such as cameras and tape recorders.

- The design does not depend on rigidity provided by structural members within the sensory cylinder, preserving flexibility for future changes.

The most striking growth and evolution has taken place in the sensors and experiments embarked in the Nimbus series. A summary of the sensors carried in Nimbus I, II, III, and IV, and those proposed for follow-on spacecraft is presented in Table 1. Nimbus spacecraft have been used to develop all of the new detectors which have been fed into the operational meteorological satellite system. The sensors tested include cloud camera systems and infrared radiometers, an infrared spectrometer, an interrogation and location system, and ultraviolet radiometers and spectrometers. Microwave spectrometers and radiometers are programmed for Nimbus E, while the instrumentation for Nimbus F is still being defined.

. <u>Launch Vehicles</u>

Nimbus I exceeded its design weight goal of 650 pounds, and as it threatened to exceed the capability of the Thor-Agena launch vehicle to place it into a 600 n.m. polar orbit (800 pounds) it was necessary to remove the Medium Resolution Infrared Radiometer (MRIR) experiment from the spacecraft. Nimbus II and III were launched by the Thrust-Augmented Thor-Agena, which can place 1500 pounds into the Nimbus orbit; this capability appears to be adequate for foreseeable experiment requirements through Nimbus F.

. <u>Performance</u>

<u>Nimbus I</u>. Nimbus I was launched August 28, 1964; an early burnout of the launch vehicle put it into an elliptic orbit of 503 by 228 nautical miles, instead of the desired 600 mile circular orbit. A total of 27,000 weather photographs were sent during the spacecraft's 27 day lifetime, during which period it met all of its flight objectives except for achieving six months' operation.

- Nimbus II. Nimbus II was launched into a 590 by 636 n.m. orbit on May 15, 1966. It functioned for almost three years, far exceeding its expected six month lifetime and demonstrating the correction of the condition which caused Nimbus I's early failure. It transmitted more than one million day and night photos of the earth. The results achieved by the High Resolution Infrared Radiometer were outstanding. The spacecraft's tape recorders failed after six months of operation; weather data was thereafter transmitted to ground stations in real time. Tape recorders have been a continuing source of trouble in the program. Since they are required for high-capacity data storage, effort continues to design recorders combining wide bandwidth, high data capacity, and long life.

- Nimbus B. This spacecraft suffered a launch failure in May, 1968.

- Nimbus III. Launched April 14, 1969, Nimbus III has completed more than one year in orbit, and all sensors except the Infrared Interferometer Spectrometer (IRIS) continue to operate satisfactorily. IRIS ceased to function July 22, 1969, and the high data rate storage system (HDRSS) tape recorders are degrading due to tape wear and flutter problems. Nimbus III has greatly enhanced weather forecasting by measuring the atmosphere's vertical temperature profile, water vapor profile, ozone distribution, and nitrous oxide and methane distribution, all on a global basis. It also demonstrated the capability of the SNAP-19 to supply 50 watts of regulated power and the ability of the Interrogation, Recording, and Location System (IRLS) to locate and interrogate sensors for data relay to a central ground station.

- Nimbus IV. Weighing 1366 pounds, Nimbus IV was launched April 9, 1970, and early results indicate it will transmit the most information on the atmosphere ever returned from space.

Projected Launches

Nimbus E and F are scheduled to be launched in May, 1972 and June, 1973 respectively, and will carry advanced meteorological and experimental payloads.

Both programs are in the advanced planning stages; it is expected that the spacecraft configurations will be similar to Nimbus IV.

Post-Nimbus Planning

Looking beyond Nimbus F, it appears that the growing number of meteorological experiments to be tested, coupled with larger antennas and an increasing requirement to look to the side as well as directly down, may find the existing Nimbus design to be space-limited. The earth-viewing area of the current spacecraft, which is a circular platform about five feet in diameter, is especially limiting. Antennas for microwave experiments are relatively large compared to their counterparts in the infrared, visible-light, and ultraviolet experiments carried in Nimbus I through IV. Studies have been initiated to formulate concepts for a spacecraft carrying up to 20 experiments, with a payload weighing 2 1/2 times the present one, and a power consumption of 400 watts of electrical power. It appears likely that Nimbus F will be the last of the series. The next generation meteorological research satellite is tentatively being referred to as the Unified Nimbus Observatory (UNO).

Summary of Development

The Nimbus family of observatory spacecraft is carrying out the task of supporting the meteorological satellite research and development program over a period that will span almost fifteen years. This does not mean that the Nimbus launched in the mid-1970's will be the same as the one whose design was initiated in 1960, but the family resemblance will be striking. The basic design stressed flexibility to facilitate spacecraft subsystem and sensor modification and evolution as the program progressed, and Nimbus performance to date has demonstrated that the correction of deficiencies and the accommodation of more numerous and diverse sensors in succeeding flights has been feasible and extremely successful. Nimbus IV, launched in 1970, reflects the current state-of-the-art in its subsystems, and its complement of experiments returns to earth a variety and quality of meteorological data never before gathered by a satellite, while its design shows considerable commonality with previous Nimbus spacecraft. The major developments as the series has progressed have been:

- Nimbus II
  - Added MRIR experiment
  - Redesigned solar array drive system

- <u>Nimbus III</u>

  - Added 3 new meteorological experiments, 2 of them directed at atmospheric spectrometric sounding.

  - Expanded the capacity of the command subsystem

  - Expanded the data system to handle diverse sensor requirements and to provide additional storage capability for full global coverage.

  - Enlarged the power supply capability and added a 50 watt Radioisotope Thermoelectric Generator. Coupled with the expanded data system, this permitted continuous and concurrent operation of all experiments and the collection of all data on a global basis.

- <u>Nimbus IV</u>

  - Increased sensor complement to 9 meteorological experiments, 4 of them new.

  - Refined attitude control subsystem.

- <u>Future trends</u>. Work to improve the performance of follow-on Nimbus spacecraft is continuing in these areas:

  - <u>Longer-lived systems</u>

    Tape recorders.
    Improved bearings and lubricants.
    Precise attitude sensors.
    Radiation-resistant solar cells
    Storage batteries.

  - <u>Data systems</u>

    New concepts for data storage, compaction and retrieval.

  - <u>Sensors</u>

    Efficient infrared detectors without cryogenic cooling

High resolution TV tubes (10,000 lines).

Microwave receivers.

Radar sensors for mapping and seastate measurements.

Impact of Integrated Program Capability

The potential impact of the integrated program capability on a program such as Nimbus has been assessed by making the following assumptions:

- The low cost transportation system has a 50,000-pound payload capability to low earth orbit. This space shuttle can inject a Nimbus-type payload (weighing less than 2,000-pounds) directly into a 600 mile circular sun-synchronous orbit, and can reach that orbit for subsequent satellite servicing or to return the spacecraft to earth.[5] The cost of a space shuttle operation has been estimated as being between $5M and $8M per launch; for the purpose of making a cost comparison with the automated program, a conservative estimate of $8M per launch is used. (An interesting alternative on-orbit servicing cost model has been described by Bosch.[6] He assumes a space station already in polar orbit for purposes other than satellite servicing, as well as regularly scheduled shuttle flights between earth and the space station. The transportation system includes an inter-orbital space tug which can be used for satellite servicing. In this context, the marginal cost of satellite servicing is represented by the cost of bringing from earth into orbit the propellant required by the service vehicle; this cost model is more favorable than the one based on direct shuttle servicing.)

- Nimbus has been configured to be compatible with shuttle delivery to low earth orbit, shuttle return to earth, and on-orbit servicing.

- The Nimbus spacecraft cost is $35M, and the Thor Agena launching cost (hardware and support) is $7M. Nimbus experiments (included in the spacecraft cost of $35M) are $2M each.

Certain significant events in Nimbus operational history have been reviewed in light of the above assumptions to determine how they could have been handled had the integrated capability been available:

Spacecraft	Event	Integrated Program Response	Impact
Nimbus I	MRIR deleted before launch due to weight restrictions	Large shuttle payload capability	Full sensor complement installed
	Placed into 503 x 228 nm elliptic orbit	Space tug insert into orbit	600 nm circular orbit achieved
	Solar array drive failed after 27 days	Investigate via space tug; return spacecraft to earth; correct failure and return to orbit	Operation resumed
Nimbus II	Tape recorders failed after 6 months	Replace recorders in orbit	Full-orbit playback capability restored
	Horizon scanner failed after 32 months, ending mission	Replace scanner in orbit or return spacecraft to ground for refurbishment	Continue operation, or reclaim spacecraft for further use
Nimbus B	Launch failure	Shuttle/space tug insert into orbit	Spacecraft placed into operation; evaluation of experiments begins
Nimbus III	IRIS failed after 3 months	Replace IRIS in orbit.[7]	IRIS data continues; defective sensor returned to earth for failure analysis
	Tape recorders degrading	Replace recorders in orbit at 6 months intervals	Maintain full orbit playback capability; rebuild returned recorders (Estimate tape recorder cost at $250K, and refurbishment at $50K)

Assuming successful accomplishment of the approved program, six Nimbus research and development spacecraft will have been placed in orbit over a period of about nine years. Inasmuch as spacecraft system capabilities were significantly expanded in Nimbus III, the series can be considered as comprising two generations of spacecraft, mounting increasingly complex and sophisticated meteorological experiments. To facilitate a rough cost estimate of a man-attended meteorological research and development program of the same scope as Nimbus, a spacecraft with a nominal life of five years is assumed; two of them would thus be required to cover a nine year period comparable to the time that Nimbus satellites have been in orbit, and each is assumed to cost the same as a Nimbus satellite. The man-attended Nimbus-type test bed is serviced on orbit every six months for replacement of experiments, updating and servicing of systems, and replacement of tape recorders. Its five-year lifetime is achieved through routine replacement and repair of marginal spacecraft subsystems, obviating the need for the development of extremely expensive long-lived subsystems. A table comparing the costs of a man-attended meteorological development program with the Nimbus automated program is shown below. It indicates that the program based on the integrated capability would be competitive with the completely automated program.

	Automated Program		Integrated Program	
	Item	Cost	Item	Cost
Spacecraft	*7 Nimbus @35M	245M	2 Nimbus-type testbeds @35M	70M
Launch	*7 Thor-Agena @7M	49	2 shuttle operations @8M	16
On-orbit servicing	Not applicable	-	17 shuttle operations (2/yr) @8M	136
Experiments	Total of 39 (included in S/C cost)	-	6 installed in each S/C at launch (included in S/C cost); 27 replacements installed during semi-annual servicing trips @2M each	54
Replacement S/C systems	Not applicable	-	Assume 1M/yr	9
Total Program		294M		285M

* Includes Nimbus B (failed to achieve orbit)

Conclusions

The Nimbus program was initiated in 1960 to support the meteorological satellite research and development program; if carried out as currently approved, it will have placed six satellites in orbit by the mid-1970's. The evolution and performance of these satellites are illustrative of a class of unmanned research and development spacecraft. The role that might have been played by the integrated program capability in carrying out a similar program has been examined for purposes of comparison and evaluation.

In the context of the assumed capabilities assigned to the integrated program, it appears that a Nimbus-type meteorological research and development vehicle could be delivered to the 600 n.m. circular sun-synchronous orbit by shuttle. The spacecraft would then be maintained in operation for a period of several years, with servicing trips being scheduled on a regular basis to replace or modify the sensors being tested, to repair or replace marginal or short-lived support systems, and to replenish consumables. The manned capability minimizes the need to develop especially long-lived systems, relying rather on replacement of systems when required.

The opportunity to install new sensors at regular intervals, such as every six months, would bring experimental sensors to a state of operational use at an earlier date. Periods of up to three years have elapsed between successive Nimbus launchings; tests of modifications to sensors based on the results of observations, and the test of the next generation of experimental sensors, had to wait for the construction and launch of the next satellite. The meteorological research and development program was thus paced by spacecraft construction and acquisition schedules and budgeting considerations, rather than the shorter and less costly sensor development cycle.

A cost comparison indicates that a man-attended meteorological research and development program, based on inserting development satellites into orbit and servicing them on a regular basis on orbit, would be quite competitive with a completely automated program.

J. P. Jamison

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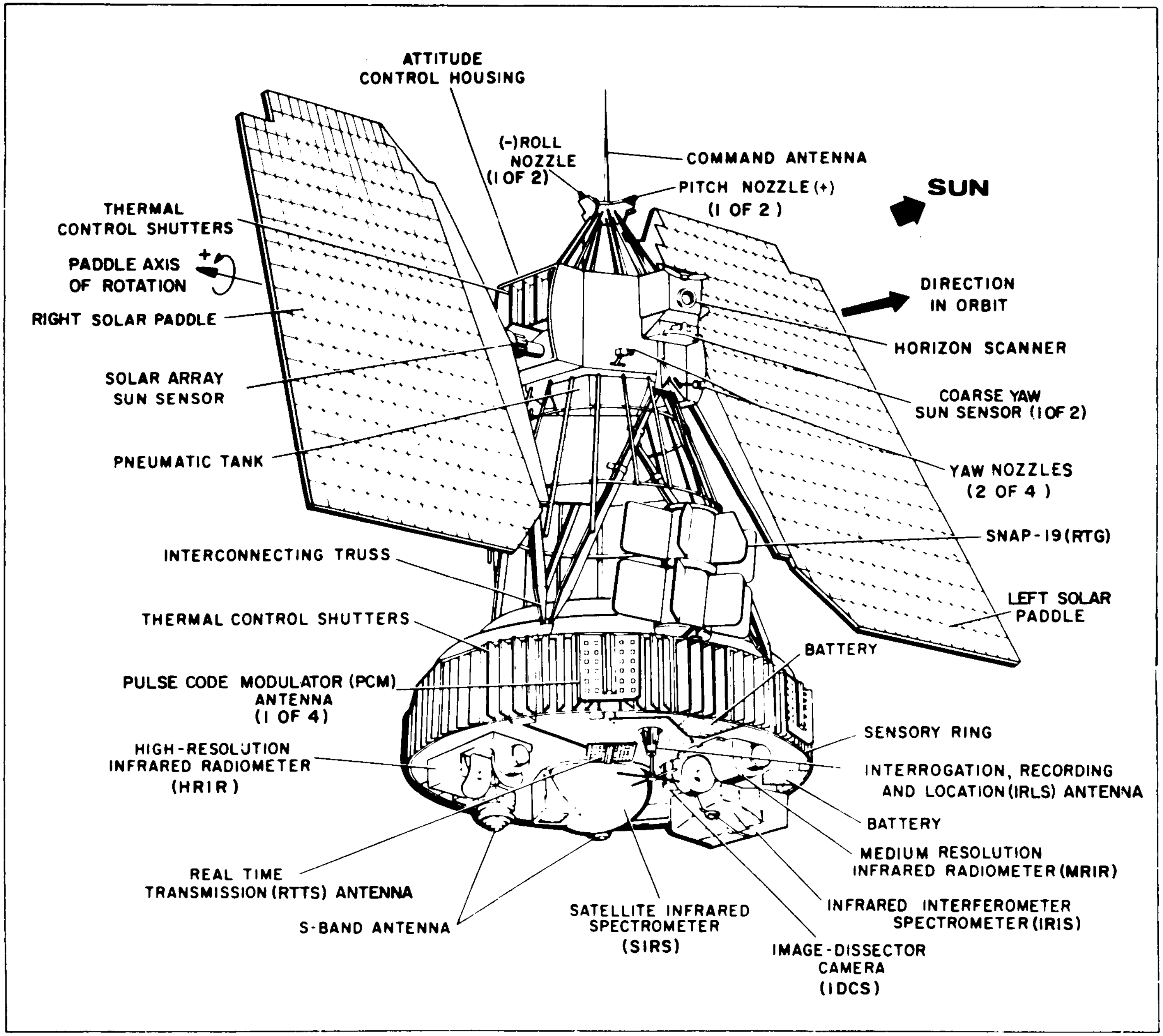

FIGURE 1 - NIMBUS SPACECRAFT CONFIGURATION

TABLE 1
NIMBUS EXPERIMENTS

	NIMBUS					
	I	II	III	IV	E	F
AVCS (ADVANCED VIDICON CAMERA SYSTEM)	σ	σ				
APTS (AUTOMATIC PICTURE TRANSMISSION SYSTEM)	σ	σ				
IDCS (IMAGE DISSECTOR CAMERA SYSTEM)			σ	σ		
HRIR (HIGH RESOLUTION INFRARED RADIOMETER)	○	○	○			
MRIR (MEDIUM RESOLUTION INFRARED RADIOMETER)		○	○			
SIRS (SATELLITE INFRARED SPECTROMETER)			● ○ ∗	● ○ ∗		
IRIS (INFRARED INTERFEROMETER SPECTROMETER)			ʍ ○ ● ∗	ʍ ○ ● ∗		
MUSE (MONITOR OF ULTRAVIOLET SOLAR ENERGY)			ʍ ∧	ʍ ∧		
IRLS (INTERROGATION RECORDING AND LOCATION SYSTEM)			‡	‡	‡	BEING
SNAP-19 (SPACE NUCLEAR AUXILIARY POWER SYSTEM) (RTG)			X			DEFINED
RMP (RATE MEASURING PACKAGE)			X			
BUV (BACKSCATTER ULTRAVIOLET SPECTROMETER)				∧		
FWS (FILTER WEDGE SPECTROMETER)				∗		
SCR (SELECTIVE CHOPPER RADIOMETER)				● ○	● ○	
THIR (TEMPERATURE HUMIDITY INFRARED RADIOMETER)				○ ∗	○ ∗	
ESMR (ELECTROMAGNETIC SCANNING MICROWAVE RADIOMETER)					ϟ	
ITPR (INFRARED TEMPERATURE PROFILE RADIOMETER)					●	
NEMS (NIMBUS E MICROWAVE SPECTROMETER)					ϟ	
SCMR (SURFACE COMPOSITION MAPPING RADIOMETER					□	

LEGEND

- ● ATMOSPHERIC TEMPERATURE PROFILE
- ∗ ATMOSPHERIC WATER VAPOR
- ○ SURFACE OR CLOUD TOP TEMPERATURE
- σ CLOUD MAPPING
- ʍ OZONE DETECTION
- ∧ MEASURE ULTRAVIOLET SOLAR ENERGY
- ϟ MICROWAVE ATMOSPHERIC SOUNDINGS
- ‡ DATA COLLECTION FROM PLATFORMS
- X SPACECRAFT SUBSYSTEMS
- □ DETERMINE SURFACE COMPOSITION